RELATION BETWEEN INTENSITY OF LIGHT AND RATE OF LOCOMOTION IN *PHACUS PLEURONECTES* AND *EUGLENA GRACILIS* AND ITS BEARING ON ORIENTATION.

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INTRODUCTION.

According to the De Candolle-Verworn theory of orientation which has been widely accepted, the action of the locomotor appendages in organisms is dependent upon the intensity of the light received by the receptors connected with them; so that if one side of a bilaterally symmetrical organism, *Volvox, e.g.*, is more highly illuminated than the other the locomotor appendages on one side beat more effectively than those on the opposite side, resulting in turning until the two sides are equally illuminated and the organism is oriented. Torrey ('13), Bancroft ('13), Loeb ('18). and others maintain that orientation in asymmetrical organisms like *Phacus* and *Euglena* is in principle precisely the same as orientation in bilaterally symmetrical organisms. These organisms rotate on their longitudinal axes and proceed on a spiral course with a given surface continuously directed outward. The locomotor appendages are, consequently, on one side when the organism is in one position on the spiral and on the opposite side when it is in another position. Owing to this it is held by those mentioned above, that orientation in these asymmetrical organisms is essentially like that in bilaterally symmetrical organisms. If this contention holds it is evident that the rate of locomotion should depend upon the luminous intensity of the field. With this in mind we have investigated the relation between the intensity of light and the rate of locomotion in *Phacus* and *Euglena*.

Phacus pleuronectes.

Phacus is a small green flagellate somewhat like *Euglena* in structure and behavior. The species studied closely resembles

Phacus pleuronectes (Müller). It was kept in the laboratory in fairly good condition for several months. All of the specimens used in these observations were taken from the same culture jar. The experiments were all carried out in a large dark room. The apparatus used was arranged as follows: A rectangular box 180 cm. long, 15 cm. wide and 15 cm. deep, open at one end and the top, was placed on a table with a microscope near the open end. An electric lamp in the box was attached to the under surface of a short board which fitted into grooves on the top of the box, and could be moved back and forth so as to rapidly change the luminous intensity at the microscope. The lamp was so adjusted and screened that it produced a horizontal beam of light which crossed the stage of the microscope. The beam of light, before reaching the organisms, passed through 3 cm. of water in a glass container. Thus the longer waves from the lamp were absorbed by the water and any possible effect of heat on the behavior of the organisms was greatly reduced, if not entirely eliminated.

All of the observations were made under the low power of a compound microscope with the organisms on the stage in an aquarium, about 3 cm. square, constructed of the best plate glass obtainable. The eye-piece of the microscope contained a micrometer scale which divided the field into equal divisions, each .017 mm. long.

In making the observations, 30 to 40 specimens of *Phacus* were taken from a culture jar and put into the aquarium, which contained clear water about 1 cm. deep taken from the same jar. The aquarium was then put into the beam of light on the stage of the microscope and the distance from the lamp adjusted so as to produce the luminous intensity desired. An individual which was accurately oriented was now selected and carefully observed as it proceeded toward the light. (All of the observations were made on positive individuals.) When the anterior end reached a cross-bar of the micrometer scale the stop-watch was started, and when it reached the cross-bar 20 divisions, .34 mm., beyond, the watch was suddenly stopped and the time consumed recorded. The intensity was then suddenly raised or lowered and the same individual again timed, in the manner just described. Thus there were two readings made on each individual. In some cases the readings were made first in the higher, and in other cases first in

the lower intensity. When the intensity was increased there was ordinarily no shock-reaction, and the organisms were timed immediately after the intensity was changed, *i.e.*, shortly after the close of the test in the lower intensity. But when it was decreased there usually was a shock-reaction, and if this occurred, the reading was not started until after the organisms had fully recovered which usually required only a few moments. The intervals preceding the readings in the lower intensities were, however, always somewhat longer than those preceding the readings in the higher intensities.

The results obtained are presented in Tables I. and II. Table

TABLE I.

RELATION BETWEEN INTENSITY OF LIGHT AND RATE OF LOCOMOTION IN *Phacus pleuronectes* (POSITIVE INDIVIDUALS).

Each line contains two readings for one individual in different intensities of light; the last line, the averages for all 20 individuals. The record in the lower intensity was obtained first in each instance.

Designation of individuals.	Time, in seconds, required to travel .34 mm. in an intensity of 1023 m.c.	Time, in seconds required to travel .34 mm. in an intensity of 4128 m.c.
1	5.7	6.2
2	5.4	5.8
3	6.7	7.4
4	5.5	5.2
5	6.4	7.0
6	7.0	7.5
7	6.2	6.2
8	7.0	7.2
9	4.9	4.4
10	6.0	5.7
11	5.5	5.4
12	5.4	5.3
13	5.4	5.3
14	5.0	4.7
15	5.2	5.2
16	4.8	4.8
17	5.0	5.2
18	4.7	4.9
19	5.2	5.0
20	5.7	5.5
Average	5.63	5.69

I. includes, for each of 20 individuals, two records, one taken in higher and the other in lower intensity. In each case the record for the lower intensity was obtained first. That is, the rate of locomotion for a given individual was ascertained in the lower intensity, then the light was moved nearer to the microscope and the rate ascertained for the same individual in the higher intensity. After the two readings had been obtained for one individual, the light was moved to its original position, another individual timed in the same way, and so on until the rates for 20 or more individuals were recorded.

By referring to Table I., it will be seen that the rate of locomotion of any one individual in the lower intensity was practically the same as it was in the higher intensity. The table shows that the average time required to travel .34 mm. was 5.63 sec. in the lower and 5.69 sec. in the higher intensity, indicating a slightly higher rate in the lower intensity. The difference referred to is, however, only .06 of a sec. This is probably within the limits of error, since a further examination of the table shows that the rate was not consistently higher in the lower intensity, 9 individuals traveling faster in the higher intensity, 8 slower and 3 at the same rate in the two intensities. That is, the rate varied about as frequently in one direction as in the other. This shows that there is, in *Phacus,* practically no difference in the rate of locomotion in luminous intensities varying from 1023 m.c. to 4128 m.c., and it indicates that locomotion is not to any considerable extent immediately related with the intensity of the illumination.

A summary of the results obtained in all of the observations made are presented in Table II. By referring to this table it will be seen that the rate of locomotion was on the average slightly higher in the lower intensities than it was in the higher, the average time required to travel 0.34 mm. being 6.002 seconds in the former and 6.134 seconds in the latter. The difference is, however, so small and inconsistent, being in favor of the higher illumination in two out of the nine sets of tests, that its significance is questionable. These results support the conclusions formulated above. They show that the rate of locomotion in *Phacus* is within wide ranges, practically independent of the intensity of

light when exposed for short periods of time, and that if light has any immediate effect on the rate, it has a retarding effect.

TABLE II.

RELATION BETWEEN INTENSITY OF LIGHT AND RATE OF MOVEMENT IN *Phacus pleuronectes* (POSITIVE INDIVIDUALS).

Records in the higher intensity obtained first in the first three sets of experiments and last in the rest.

Each line gives the average rate, for a set of individuals, in a higher and a lower intensity. Each individual represented in the averages was timed twice, once in a higher, and once in a lower intensity. The + signs in the last column indicate a higher rate in higher intensity, the — signs a lower rate in the higher intensity.

Number of Individuals.	Intensity in m.c.	Average Time, in Seconds, Required to Travel .34 mm.	Intensity in m.c.	Average Time, in Seconds, Required to Travel .34 mm.	Difference between the Time Required in the Two Intensities.
15..........	91	5.71	325	5.73	−.02
20..........	106	6.90	325	6.55	+.35
20..........	58	6.58	325	6.96	−.38
12..........	91	5.26	325	5.36	−.1
13..........	31	5.91	325	5.82	+.09
20..........	31	5.78	325	6.01	−.23
20..........	16	5.44	325	6.05	−.61
20..........	1,032	5.63	4,128	5.69	−.06
18..........	459	6.81	4,128	7.04	−.13
Total average		6.002		6.134	

Euglena gracilis.

The observations on *Euglena* were all made on one species (*gracilis*). The specimens used were obtained in laboratory cultures containing wheat, a substance which is very favorable for the growth of this species. The methods employed were precisely the same as those employed in the study of *Phacus* with the following exceptions: The observations extended over a wider range of intensities; they were made under a binocular in place of a compound microscope; and each individual was tested successively in four different intensities beginning in every case with the lowest, in place of in two different intensities beginning sometimes in the higher and sometimes in the lower; and the course was 0.74 mm. in place of 0.34 mm. long.

A summary of the results obtained is presented in Table III.

TABLE III.

RELATION BETWEEN RATE OF LOCOMOTION AND LUMINOUS INTENSITY IN *Euglena gracilis.*

Each individual was timed successively, once in each of the intensities indicated, beginning in every instance with the lowest. The time presented is, in every case, the average of that required for each of the individuals indicated to travel once over the course in the illumination indicated.

Date of Observation.	No. of Individuals.	Time, in Sec., Required to Travel 0.74 mm. in an Intensity of			
		286 m.c.	459 m.c.	853 m.c.	2106 m.c.
Jan. 19...	8	5.88	6.05	5.53	5.12
Jan. 28...	2	5.15	5.6	5.65	5.75
Jan. 28...	2	6.1	6.5	5.55	5.95
Feb. 1....	2	4.7	4.7	3.6	4.9
Feb. 1....	8	7.47	7.55	7.91	7.64
Feb. 6....	8	6.01	5.36	5.17	5.27
Feb. 7....	26	5.7	5.36	5.30	5.45
	Average....	5.858	5.873	5.53	5.725
		84 m.c.	142 m.c.	286 m.c.	853 m.c.
Feb. 8....	2	5.85	6.1	5.9	5.5
Feb. 12...	7	8.8	8.45	8.82	8.73
	Average....	7.325	7.275	7.36	7.115

This table shows that in intensities ranging in the one set of experiments from 286 m.c. to 2106 m.c. and in the other from 84 m.c. to 853 m.c. there is remarkably little difference in the rate of locomotion, the difference between the rate in the lowest intensity and that in the highest intensity being only .0276 + mm. per second in the one set and .0298 + mm. in the other. It shows that, in the time it takes *Euglena* to travel 10 mm. in the lowest intensity it would travel only a little more than 10.2 mm. in the highest intensity, and that the lowest rate is not consistently in the lowest intensity.

The results obtained consequently indicate that light in certain intensities slightly accelerates locomotion in *Euglena,* and slightly retards it in *Phacus.* Orientation cannot, however, be due to the effect on the rate of locomotion of difference in the illumination

of the sensitive tissue in different positions on the spiral course of these organisms, as is demanded by the De Candolle-Verworn theory applied to asymmetrical organisms by Torrey, Bancroft and others, for the effect on the rate is, even under the most favorable condition, so small that if orientation were dependent upon this, it would require much longer than it actually does; and moreover, orientation occurs under luminous conditions in which an increase or a decrease in intensity does not appear to appreciably effect the rate of locomotion.

The facts presented above have no bearing on the question as to the effect of light on the rate of locomotion in long exposures. All of the evidence obtained by various investigators in reference to this indicates that organisms like *Phacus* and *Euglena* come to rest if they are subjected for long periods to low illumination or darkness. This is probably owing to the effect of light on physiological processes (*e.g.*, photosynthesis) which in turn affect the activity of the organisms.

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